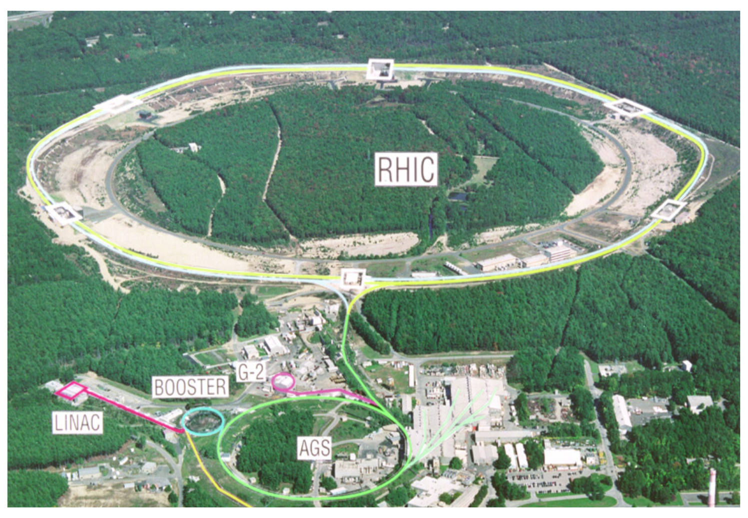
Study of transverse single-spin asymmetries in heavy flavor production in *p+p* collisions using the PHENIX Forward Vertex Detector

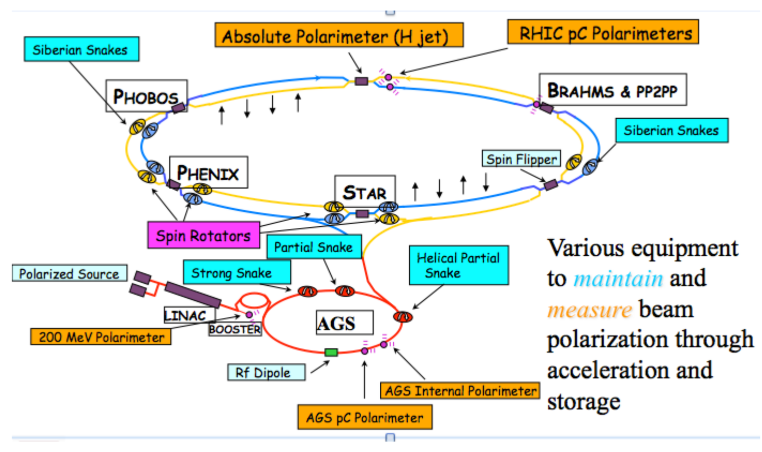
22nd International Spin Symposium

Jeongsu Bok (New Mexico State University) for the PHENIX collaboration

RHIC

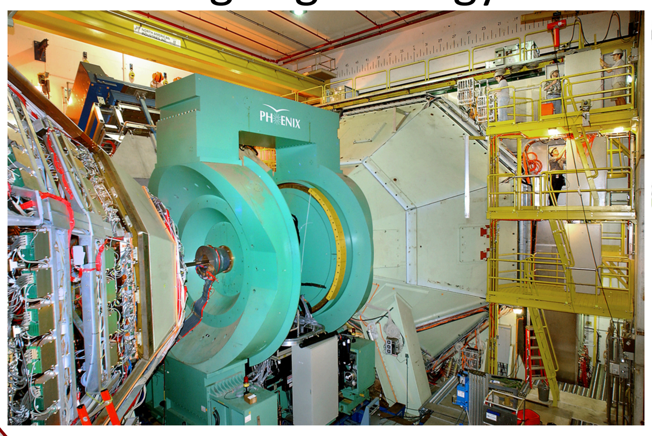
The world's only machine capable of colliding high-energy beams of polarized protons, and a unique tool for exploring the proton's spin. Also studying collisions of polarized protons with nuclei: *p*+Al and *p*+Au

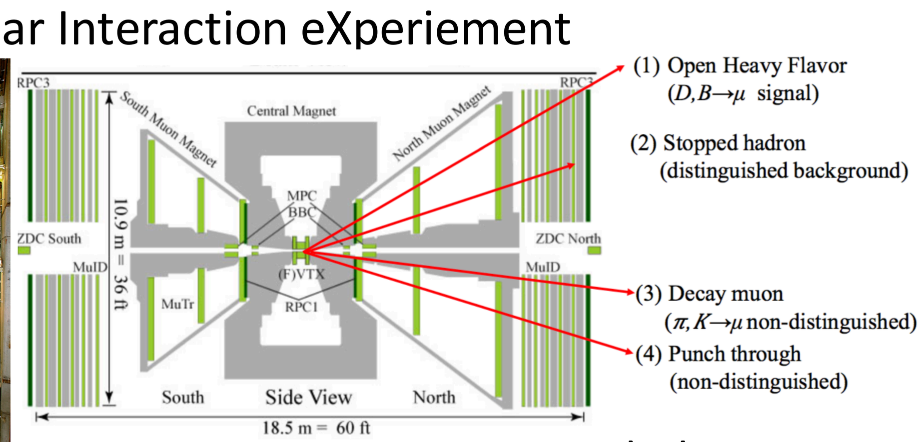




PHENIX experiment

Pioneering High Energy Nuclear Interaction eXperiement

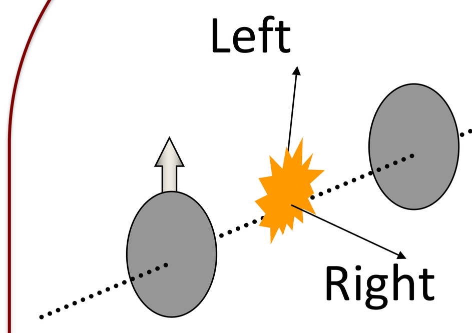




Muon Spectrometers 1.2<|η|<2.4

FVTX+MUTR+MUID+RPC

Transverse Spin with Open Heavy Flavor



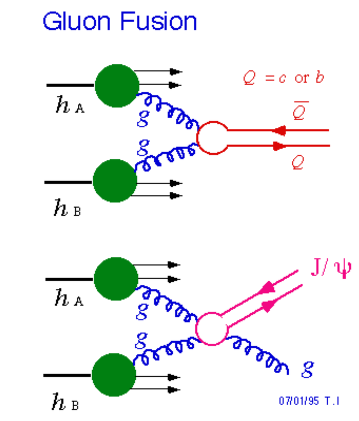
$$A_N = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}}$$

Large Single Spin Asymmetries (SSA) were observed in meson production in the forward direction in p+p collisions at center-of-mass energies from 7.7 GeV to 200 GeV:

Mechanisms for A_N

	Initial State	Final State
Transverse Momentum Dependent function approach	**Sivers mechanism** D. Sivers, PR D41 (1990) 83; D43 (1991) 261 $A_N \propto f_T^q(x, k_\perp^2)\cdot D_q^h(z)$ Siver's Effect (PDF) Proton spin and quark k_T correlation	**Collins mechanism** John Collins, Nucl Phys B396 (1993) 161 $A_N \propto \delta q(x)\cdot H_1^\perp(z_2, \bar{k}_\perp^2)$ Transversity (PDF) ⊗ Collin's Effect (FF) Proton spin and quark spin correlation; Quark spin and hadron k_T correlation
Collinear Factorization: $k_\perp$ is integrated ➔ represent integrated spin dependence of the partons transverse motion	**Twist-3 distribution** $d\sigma(\mathbf{S}_\perp) = H\otimes f_{a/p^\uparrow(3)}\otimes f_{b/p(2)}\otimes D_{h/c(2)} + H'\otimes f_{a/p^\uparrow(2)}\otimes f_{b/p(3)}\otimes D_{h/c(2)} + H''\otimes f_{a/p^\uparrow(2)}\otimes f_{b/p(2)}\otimes D_{h/c(3)}$; works at $Q >> \Lambda_{QCD}$, Twist-3 quark-gluon correlation function $T_{q,F}$ and Two independent tri-gluon correlation functions $T_G^{(f)}$, $T_G^{(d)}$ are related through $T_F^q(x,x) = -\int d^2\mathbf{p}_\perp \frac{\mathbf{p}_\perp^2}{M} f_{1T}^{\perp q}(x,\mathbf{p}_\perp^2)\vert_{SIDIS}$	**Twist-3 fragmentation** Twist-3 fragmentation function $\hat{H}$ is related to the $k_\perp$-moment of the TMD Collins function $H_1^{\perp h/q1}$ as $\hat{H}^{h/q}(z) = z^2\int d^2\vec{k}_\perp \frac{\vec{k}_\perp^2}{2M_h^2} H_1^{\perp h/q}(z, z^2\vec{k}_\perp^2)$

The TMD approach needs two momentum scales and is therefore used in SIDIS and DY, while the collinear approach needs only one momentum scale and is therefore used in inclusive *p+p* A_N's



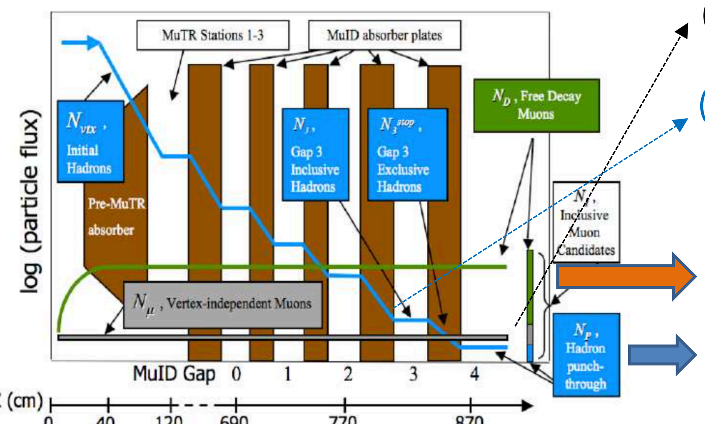
Heavy Flavor (D/B meson) production is an ideal tool for investigating gluon distribution. A_N in heavy flavor production is sensitive to tri-gluon correlations by using the twist-3 collinear factorization framework

Z. Kang, J. Qiu, W. Vogelsang, F. Yuan, PRD78:114013 (2008)

Y. Koike, S. Yoshida PRD84:014026 (2011)

Open Heavy Flavor A_N Analysis – s/b ratio

relative flux of single muon candidates



(1)Open Heavy Flavor (*D,B→μ* signal), *J/ψ→μ*

(2) Stopped hadron (distinguished background)

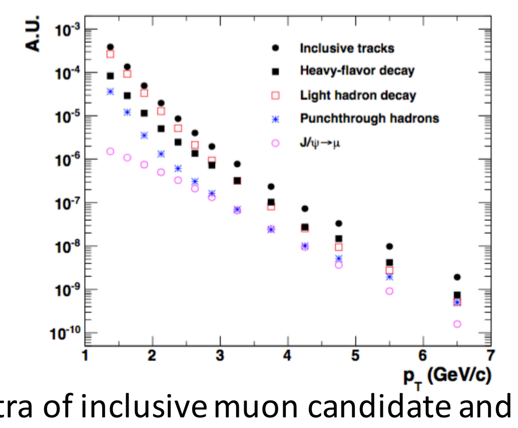
(3) Decay muon (*π,K→μ* non-distinguished)

(4) Punch through (non-distinguished)

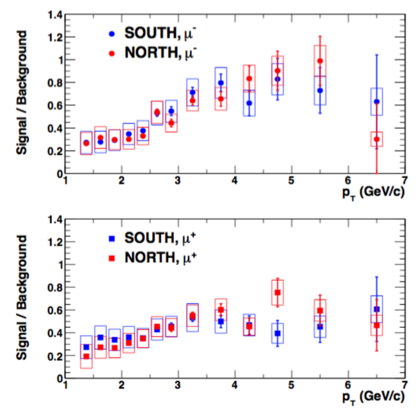
$$N_{HF} = N_{Incl}/\varepsilon_{trig} - N_{DM} - N_{PH} - N_{J/\psi\rightarrow\mu}$$

In order to estimate the light hadron background (N_{DM},N_{PH}), a hadron cocktail method was used.

- N_{DM} : Decay muons from $\pi^{\pm}$ and $K^{\pm}$ are the dominant background p_T<5 GeV/c. It shows a linear dependency on z_{vtx}
- N_{PH} : Punch-through hadron background becomes larger at p_T>5GeV/c, can be estimated by matching the p_T distribution of stopped hadrons at the MuID Gap3
- $N_{J/\psi\rightarrow\mu}$: *J/ψ→μ* decay is relatively small at low p_T region, ~20% of N_{HF} at p_T>3GeV/c



p_T spectra of inclusive muon candidate and background sources from hadron cocktail simulation.



signal-to-background ratio Run12 p+p 200GeV

Open Heavy Flavor A_N Analysis – Asymmetry

Maximum Likelihood Method

$$\mathcal{L} = \prod(1 \pm P\cdot A_N cos(\phi_i))$$

$$\log\mathcal{L} = \sum\log(1 \pm P\cdot A_N cos(\phi_i))$$

$$\sigma^2(A_N) = (-\frac{\partial^2\mathcal{L}}{\partial A_N^2})^{-1}$$

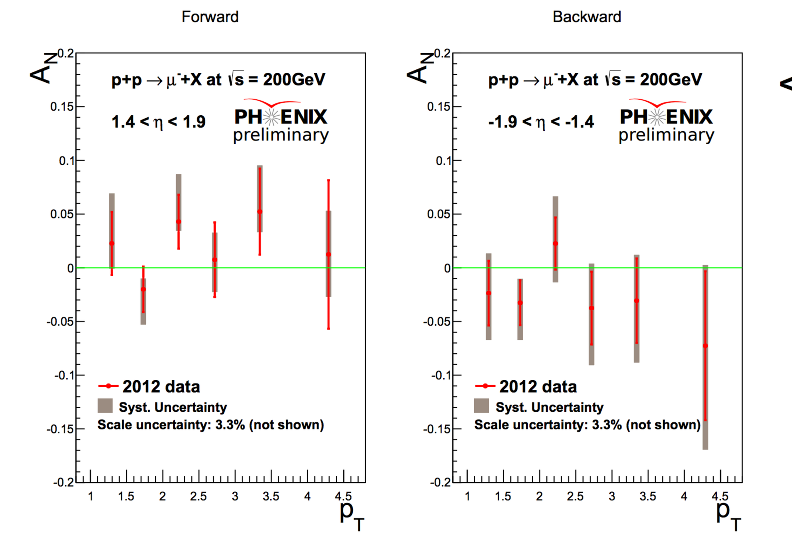
- *P* : polarization
- ϕ_i : azimuthal angle of each track
- Each A_N value maximizing the Log$\mathcal{L}$ is the final A_N
- crosscheck of A_N by fitting A_N cos(ϕ_i) for

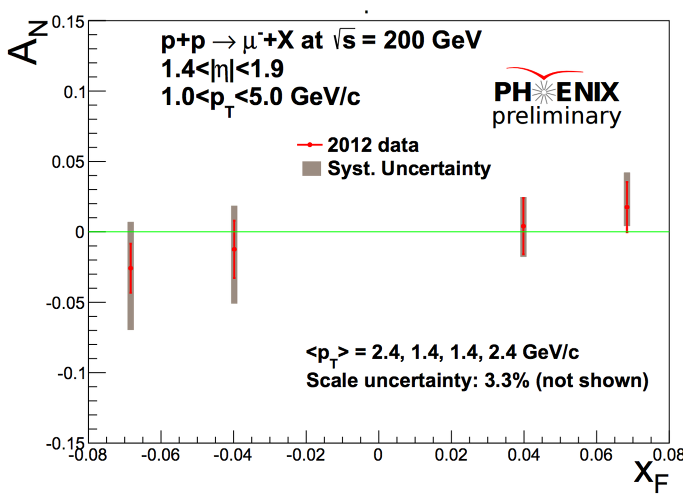
$$A_N(\phi) = \frac{\sigma^{\uparrow\uparrow}(\phi)+\sigma^{\uparrow\downarrow}(\phi)-\sigma^{\downarrow\uparrow}(\phi)-\sigma^{\downarrow\downarrow}(\phi)}{\sigma^{\uparrow\uparrow}(\phi)+\sigma^{\uparrow\downarrow}(\phi)+\sigma^{\downarrow\uparrow}(\phi)+\sigma^{\downarrow\downarrow}(\phi)} = \frac{1}{P}\cdot\frac{N^{\uparrow\uparrow}(\phi)+R_1\cdot N^{\uparrow\downarrow}(\phi)-R_2\cdot N^{\downarrow\uparrow}-R_3\cdot N^{\downarrow\downarrow}}{N^{\uparrow\uparrow}(\phi)+R_1\cdot N^{\uparrow\downarrow}(\phi)+R_2\cdot N^{\downarrow\uparrow}+R_3\cdot N^{\downarrow\downarrow}}$$

$$A_N^{HF} = \frac{A_N^{incl} - f_h\cdot A_N^h - f_{J/\psi}\cdot A_N^{J/\psi\rightarrow\mu}}{1 - f_h - f_{J/\psi}}$$

$$\delta A_N^{HF} = \frac{\sqrt{(\delta A_N^{incl})^2 + f_h^2\cdot(\delta A_N^h)^2 + f_{J/\psi}^2\cdot(\delta A_N^{J/\psi\rightarrow\mu})^2}}{1 - f_h - f_{J/\psi}}$$

- A_N^{HF} : Muons from Heavy Flavor
- A_N^{incl} : MUID Gap4 tracks : the light hadron background, *J/ψ→μ* background, and *D/B→μ* signal
- A_N^{h} : MUID Gap3 tracks are stopped (light) hadron
- $A_N^{J/\psi\rightarrow\mu}$: *J/ψ→μ* contribution *(Phys. Rev. D 85, 092004(2012))* calculated by toy simulation and $A_N^{J/\psi}$ *(Phys. Rev.D86,099904(2012))*
- f_h : fraction of the light hadron background
- $f_{J/\psi}$: fraction of *J/ψ* background

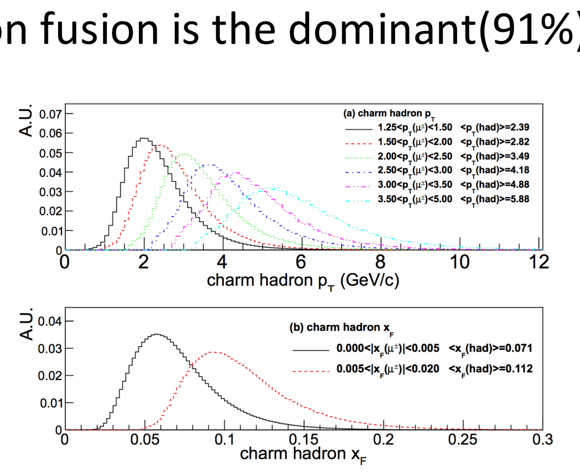




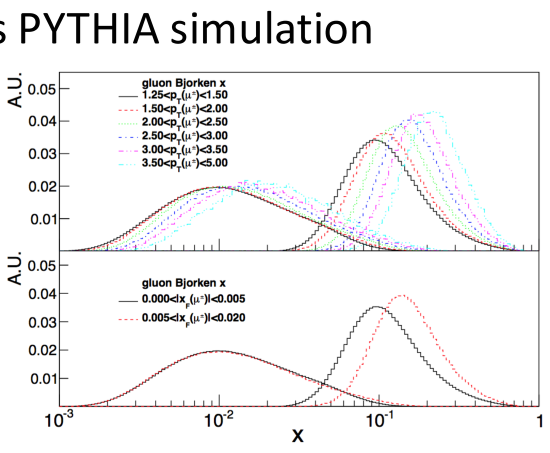
Asymmetries from 2012, 200 GeV RHIC *p+p* data ($\mathcal{L}_{int}$=9.2pb^{-1}, P_{Blue}=64%, P_{Yellow}=59%) were studied for both charges, will be released very soon.

Open Heavy Flavor A_N Analysis - PYTHIA

- We measured A_N (openHF →*μ*) in muon p_T, x_F bin
- PYTHIA simulation to estimate p_T, x_F of parent charm hadron (mostly D meson) for the $\mu^{\pm}$ kinematic region 1.25<p_T ($\mu^{\pm}$)<5.0, 0.0<|x_F($\mu^{\pm}$)|<0.2 and 1.4<|y($\mu^{\pm}$)|<2.0 corresponding to this analysis
- gluon fusion is the dominant(91%) process in this PYTHIA simulation

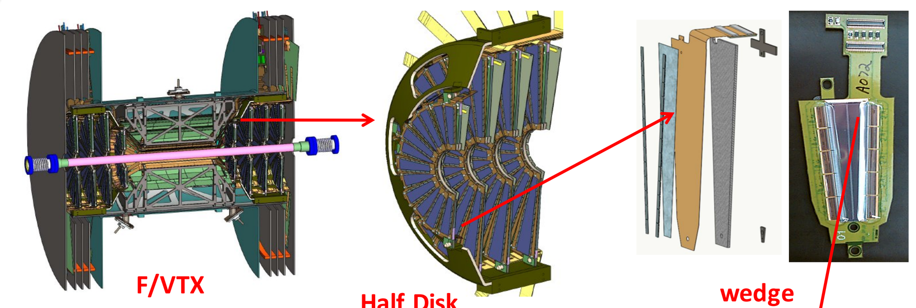


p_T and x_F distributions of parent charm hadrons in PYTHIA simulation show strong correlation between charm hadron and muon



gluon Bjorken x distribution for charm hadron →$\mu^{\pm}$ from PYTHIA simulation for each p_T(μ)and x_F(μ)bin

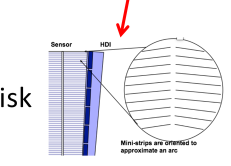
Further study – c/b separation with FVTX

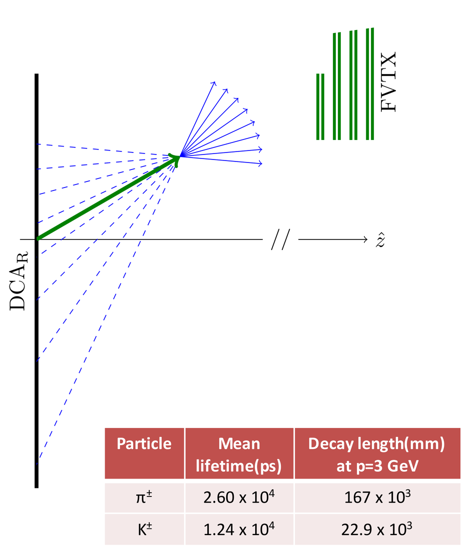


•The Forward Silicon Vertex Detector (FVTX) covers 1.2<|η|< 2.4 2π in ϕ, 18.5 cm < |z| < 38 cm

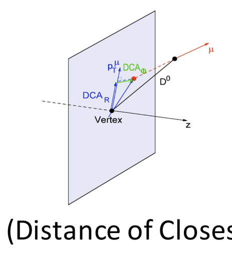
• 4 disks(3 large, 1 small) per arm(N,S), 48 Modules per disk

• 3.75° per half module/column, 75 μm radial pitch

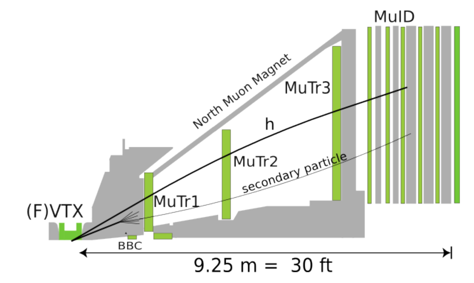


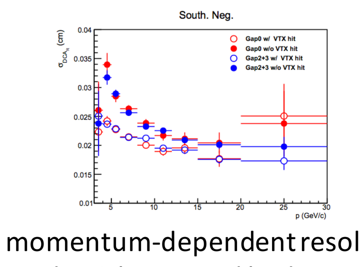


Particle	Mean lifetime(ps)	Decay length(mm) at p=3 GeV
$\pi^{\pm}$	2.60 x 10^4	167 x 10^3
$K^{\pm}$	1.24 x 10^4	22.9 x 10^3
D^0	0.410	0.197
B^0	1.530	0.261



- DCA_R (Distance of Closest Approach, R) : reconstructed vertex projected on muon p_T direction (FVTX has better resolution onto R direction)
- Prompt particles affected only by DCA_R resolution.
- Decays from HF produce additional asymmetric tails.
- Positive DCA_R tail suppressed because of FVTX acceptance.

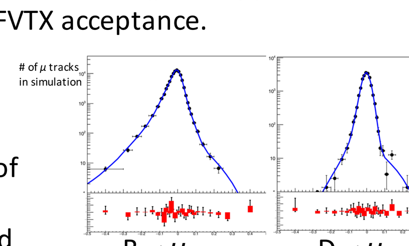




momentum-dependent resolution study with stopped hadrons

FVTX-MuTr matching and DCA_R requirements remove background of secondary particles from the back of the absorber

- 2015 *p+p* data : $\mathcal{L}_{int}$=50pb^{-1} (5x statistics of 2012 *p+p* data)
- More statistics in A_N^h with new trigger and MUTR-FVTX tracking
- 2015 First polarized $p^{\uparrow}$+A run : $p^{\uparrow}$+Au, $p^{\uparrow}$+Al
- c/b separation will allows us to study A_N for charm and bottom separately



B→*μ* 2<p_T<3GeV

D→*μ* 2<p_T<3GeV

Acknowledgement

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